

**DIELECTRIC PROPERTIES OF LIQUID
1,1-DICHLORO-2,2,2-TRIFLUOROETHANE (HCFC 123) AND
1,1-DIFLUOROETHANE (HFC 152a)¹**

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ABSTRACT

This paper presents measurements of the dielectric constant of HCFC 123 and HFC 152a, as a function of pressure and temperature, in the temperature range from 200 to 300 K and pressures up to 18 MPa, using a direct capacitance method. The samples used had a stated purity 99.8 and 99.9% respectively. The uncertainty of the results obtained for the dielectric constant was estimated at a 95 % confidence level to be $\pm 7.27 \times 10^{-3}$ for HCFC 123 and $\pm 3.26 \times 10^{-2}$ for HFC 152a.

The data obtained were correlated as a function of pressure and temperature with an uncertainty of ± 0.01 for HCFC 123 and ± 0.12 for the HFC 152a, and as a function of density and temperature with an uncertainty of ± 0.005 for HCFC 123 and ± 0.034 for HFC 152a.

The theory developed by Vedam et al., and adapted by Diguet, and the Kirkwood modification of the Onsager equation for the variation of the modified molar polarization with temperature and density were applied to analyze the data and to obtain the dipole moment of both refrigerants in the liquid state, found to be 2.13 D for HCFC 123 and 3.69 D for HFC 152a.

Key words: density; dielectric constant; dipole moment; HCFC 123; HFC 152a; Kirkwood equation; Vedam equation

1. INTRODUCTION

The problems of the ozone layer and the global warming effect are now very well established. Since the discovery of the source of these problems by Rowland and Molina (1974), several new refrigerants have been proposed to replace the existing ones, either class B (with fluorine and chlorine) or class A (only with fluorine).

Included in our research program on thermophysical properties of these new refrigerants, the dielectric constant of HCFC 141b, HCFC 142b, HCFC 123, HFC 134a, HFC 152a, HFC 32, HFC125 and HFC 143a was measured as a function of temperature and pressure, in the liquid phase. In previous papers data of HCFC 141b, HCFC 142b, HFC 134a and HFC 32 have been presented [1-6]. The present paper reports data of HCFC 123 and HFC 152a. Data of HFC 125 and HFC 143a are being processed and the theories are being tested; this work will be scope of a future paper. It is also under study the measurement of blends with industrial interest.

The importance of the study of the dielectric constant is twofold: it can provide information about the behavior of the molecules under the influence of an electric field, external or internal, dipole moments and polarizability; secondly, correlations for industrial purposes can be obtained using semi-empirical hypothesis, Vedam et al. [7,8]. Tests of PVT data can also be made, determining the coefficients of isobaric expansion and isothermal compressibility, and the virial coefficients.

2. EXPERIMENTAL

Details of the experimental set up can be found in previous publications [1,2,4,5]. For HCFC 123, which is liquid at ambient pressure and temperature, the pressure control was made by a manual pressure generator HIP (model 75-6-5). For HFC 152a the

liquefaction and pressurization was provided by an air operated double stage diaphragm compressor (Newport Scientific, model 46-14021-2). The temperature was controlled by a commercial cryostat Julabo (FPW90-SC). All the circulating lines were isolated with neoprene and the liquid bath containing the pressure vessel was isolated with polyurethane. A thermal stability of ± 0.0025 °C during half an hour was obtained. A period of twelve hours is required after each temperature change. The temperature measurements were performed with a calibrated platinum resistance thermometer PT-100 (at 4 points) using a 5 1/2 digital multimeter (Keithley, model 199 DMM). This instrument was also calibrated with three standard resistors.

The samples used were supplied by Solvay Fluor und Deviative, GmbH (German); HCFC 123 had a stated purity of 99.8 % , with a water content of 25 ppm. HFC 152a had a stated purity of 99.9 % , and no water content was referred. The samples were used without further purification. Molecular sieves from Dupont (USA) activated under vacuum at 150 °C during 24 hours were used to reduce the water content. The period of contact with the samples was approximately six hours. After this treatment the samples are supposed to be water free.

3. RESULTS

The static dielectric constant was obtained from the ratio of the capacitance of the cell with the sample - C and the empty cell - C_0 . The measurements of the capacitance under pressure were performed with intervals of 1 MPa from the saturation line up to the maximum pressure (205-213 K and pressures up to 15 MPa for HCFC 123 and 207-298 K and pressures up to 18 MPa for HFC 152a). Cycles of compression and decompression along each isotherm were performed in order to test the reproducibility of

the instrument. The isotherms are spaced of 10 K from each other (13 and 11 respectively). From one sample to another the system is evacuated and kept at 50 °C for the complete cleaning. Table 1 presents the experimental data obtained for HCFC 123 and the Table 2 for HFC 152a.

The calculation of the uncertainty associated with the measurement of the dielectric constant was based in the determination of the errors of the different variables that affect the calculation of ϵ , to say, T , P , C and C_0 . The values used for each of these variables were 0.1°C, 0.01 MPa, 0.0019 pF and 0.0023 pF, respectively. The values of the derivatives $\left(\frac{\partial \epsilon}{\partial X_i} \right)_{X_j}$ where calculated from the experimental measurements and the final uncertainty was obtained, for a 95% confidence level, from $u = 2 s_e$. A value of $\pm 7.27 \times 10^{-3}$ was obtained for HCFC 123 and of $\pm 3.26 \times 10^{-2}$ for HFC 152a.

The density values for HCFC 123 were obtained using an EOS based on the hard sphere model (attractive part) and on the De Santis equation (repulsive part) [9,10]. This EOS allows the evaluation of the density of liquid refrigerants (pure and mixtures) with an uncertainty better than 1.5% for $T/T_c < 0.9$, but of the order of 1% in the experimental range studied.

The density of HFC 152a was calculated with the Tillner-Roth and Baehr EOS [11]. This equation is based on the dimensionless Helmholtz energy with an ideal gas property part and another residual one, with a total of 21 terms. The density calculated with this equation has an uncertainty better than $\pm 0.1\%$. The data was corrected for nominal temperatures (last column). Figures 1 and 2 present the graphical plot of HCFC

123 data of ϵ versus P and ϵ versus ρ , respectively. Similar plots for HFC 152a are presented in figures 3 and 4.

From these plots it can be concluded that $(\frac{\partial \epsilon}{\partial P})_T$ is positive and $(\frac{\partial \epsilon}{\partial T})_P$ is negative. The same conclusions were obtained for the other refrigerants studied [1-6]. However $(\frac{\partial \epsilon}{\partial r})_T$ is always positive.

The data of ϵ obtained was fitted to equations in pressure P, of the form:

$$\epsilon(T, P) = a_0 + a_1/T + b_0 P + b_1 P/T \quad (1)$$

and density r :

$$\epsilon(T, r) = c_0 + c_1/T + d_0 r + d_1 r/T \quad (2)$$

Table 3 presents the values of the coefficients and their standard deviations, while on figures 5 and 6 deviations of the experimental data from equations 1 and 2 are presented. It can be seen that eq. (1) is capable of reproducing the experimental data with a maximum deviation of ± 0.01 for HCFC 123 and ± 0.12 for HFC 152a, at a 95% confidence level. Eq. (2) gives a much better representation, 0.005 and 0.034, respectively.

DISCUSSION

An exhaustive bibliography research led to the conclusion that unfortunately there are very few data of ϵ of alternative refrigerants and specially in the liquid phase.

The only data available for HCFC 123 was obtained by Tanaka et al [12] for isotherms between 298 and 323 K and up to 35 MPa, which are outside the thermodynamic range of the present data.

However an extrapolation was tried and the conclusion is that our data are approximately 6% lower than the ones of Tanaka et al. Similar comparison of our HCFC 141b [4] data with this author revealed a deviation of 1.8%. They are not in accordance with the claimed accuracy of the instruments (0.7% for Tanaka et al). We believe that there are several sources of error namely, the extrapolation, the water content and other small impurities that may affect the final results, as these compounds are extremely good solvents.

The dependence of the dielectric constant on density was studied using the concept of Eulerian strain based on the work of Vedam et al [7,8]. and Diguet [13], as explained in previous papers [2,4,5]. The reader is referred to these publications for

details. If we define an Eulerian strain as $\Sigma = \frac{1}{2} \left[\left(1 - \frac{\mathbf{r}}{\mathbf{r}_0} \right)^{\frac{2}{3}} \right]$ and $\Delta = \mathbf{e}^{\frac{1}{2}}(\mathbf{r}) - \mathbf{e}^{\frac{1}{2}}(\mathbf{r}_0)$,

a linear dependence can be observed between Δ and Σ

$$\Delta = A\Sigma + B, \quad (3)$$

independent of the type of molecules, its nature and shape. In fact, the criteria of linearity can be used to test the existing EOS and sometimes even the credibility of PVT data.

The reference density was taken as the saturation values for each isotherm. These values were evaluated using the EOS developed by McLinden and Didion [14]. Values of A and B for HCFC 123 are presented on Table 4 and the graphical form can be seen on fig. 7 for all the isotherms studied. The same presentation for HFC 152a is in Table 5 and fig. 8.

An extended study involving several refrigerants led to the conclusion that the variation of Δ with Σ is linear; other conclusions are that the slope is negative and $B \approx 0$.

So the concept of Eulerian strain for the interpretation of the dielectric constant with density is successful. If we assume that $B=0$ than the dependence assumes a simplified form

$$\Delta = A \Sigma \quad (4)$$

and the new values are presented on Tables 4 and 5.

The deviation of ϵ thus obtained for several liquids shows a very good agreement ($\sigma=0,02\%$) with the experimental data, except for one isotherm of HFC 134a (0.1%). A consequence of this treatment is that we can obtain the dependence of the dielectric constant of the density, at a given temperature, if A' is known, as:

$$\epsilon^{1/2}(\mathbf{r}) = A' \mathbf{S} + \epsilon^{1/2}(\mathbf{r}_{sat}) \quad (5)$$

The value of $\epsilon^{1/2}(\mathbf{r}_{sat})$ is also given in Tables 4 and 5.

Since a long time ago, science has tried to understand the dielectric behavior of the liquid phase; the theory developed by Kirkwood using the definition of Onsager's local field in a liquid assembly of permanent dipoles is well known [15-17]. With this theory it is possible to correlate the dielectric constant of liquids with the apparent dipole moment.

According to Kirkwood the following relationship exists between ϵ and \mathbf{m} , the dipole moment of the free molecule (gas phase):

$$\frac{(\epsilon - 1)(2\epsilon + 1)}{9\epsilon} \frac{M}{\mathbf{r}} = \frac{4\mathbf{p}N_0}{3} \left(\mathbf{a} + \frac{g\mathbf{m}^2}{3kT} \right) \quad (6)$$

where M is the relative molecular mass of the liquid and k the Boltzmann constant. Here

g is the Kirkwood correlation factor, equal to $g = \frac{\mathbf{m}^*}{\mathbf{m}^2} = 1 + \sum_{i=1}^{\infty} z_i \langle \cos \mathbf{g}_i \rangle$ and \mathbf{m}^* the

apparent dipole moment in the liquid phase. The concept of local approximation was replaced by a region containing the molecule and its z nearest neighbors; \mathbf{g} is the angle

between the dipole moment of the central molecule and the dipole moments of the molecules in the vicinity. The Kirkwood factor gives a measure of the restriction to the rotation exerted by a central molecule over the surrounding ones [16,17].

From the representation of the l.h.s. of eq. (6) as a function of $1/T$ we can obtain the apparent dipole moment, if the slope is constant. Indeed this is the case as shown in a previous publication [4]. It can be concluded (as for all the fluids mentioned previously) that this relationship is true and independent of density. The dipole moment and the correlation factor g are presented on Table 7. This table replaces the table presented in ref. 10, as it includes the correct dipole moment in the gas phase determined by the authors in Canada [5], and the value recently calculated for HFC 32. The other data for the gas phase dipole moments were taken, as before, from the work of Meyer and Morrison [18,19], included in the NIST REFPROP database [20].

In ref. [4] we have discussed the relation between g and the restricted rotation in the liquid state, by comparing the dipole moments for the gas phase and the liquid phase. The new results show that HFC 32 and HFC 152a have the strongest value of mr^* , but it is HFC 134a that has the greater value of g . In addition HCFC 123 is the fluid that has the smaller dipole moment in both phases, but has an intermediate value of g , as HFC 152a. The fluids now measured have therefore some rotation hindered in the liquid phase, greater than HCFC 141b and HCFC 142b, but can rotate more than HFC 134a and HFC 32. Measurements with HFC 125 and HFC 143a currently being done will increase our knowledge of the behavior of these molecules in the liquid state.

CONCLUSION

This paper presents data for the dielectric constant of HCFC123 and HFC152a as a function of pressure and temperature, with an estimated uncertainty of $\pm 7,27 \times 10^{-3}$ for HCFC 123 and $\pm 3,26 \times 10^{-2}$ for HFC 152a at a 95 % confidence level. Analysis of the data was made using the Kirkwood function and Eulerian formalism.

It can be concluded that the application of the Eulerian formalism to the dielectric constant data is successful, but some future theoretical work is needed in order to obtain a coherent set of conclusions. However it is a powerful estimation method for the dependence of the dielectric constant at a given temperature. In addition the data recently obtained of HFC125 and HFC 143a, and the future study of blends will contribute to clarify all these problems.

The Kirkwood factor and the values obtained for the dipole moments in the liquid phase are consistent with the present knowledge of the molecular structure of these molecules.

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TABLE 1 – Values of Dielectric Constant of HCFC 123

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$e(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$e(T_n,p)$
$T_n=312.91$ K					
312.90	0.230	1406.01	4.1342	1405.97	4.1304
312.90	1.110	1409.17	4.1434	1409.14	4.1387
312.91	2.120	1412.71	4.1545	1412.71	4.1482
312.91	3.135	1416.19	4.1655	1416.19	4.1578
312.91	4.125	1419.53	4.1759	1419.53	4.1671
312.91	5.120	1422.82	4.1863	1422.82	4.1765
312.91	6.145	1426.13	4.1965	1426.13	4.1861
312.91	7.140	1429.28	4.2067	1429.28	4.1955
312.91	8.110	1432.29	4.2164	1432.29	4.2047
312.91	9.140	1435.42	4.2263	1435.42	4.2144
312.91	10.12	1438.36	4.2356	1438.36	4.2236
312.91	11.10	1441.23	4.2447	1441.23	4.2328
312.91	12.13	1444.19	4.2544	1444.19	4.2425
312.91	13.16	1447.10	4.2636	1447.10	4.2522
312.91	14.14	1449.84	4.2723	1449.84	4.2614
312.91	15.14	1452.58	4.2811	1452.58	4.2709
$T_n=303.08$ K					
303.07	0.200	1430.84	4.3105	1430.80	4.3103
303.07	1.130	1433.84	4.3201	1433.81	4.3189
303.08	2.110	1436.91	4.3299	1436.91	4.3279
303.08	3.100	1439.99	4.3400	1439.99	4.3370
303.02	4.110	1443.22	4.3501	1443.08	4.3463
303.02	5.100	1446.18	4.3598	1446.04	4.3554
303.08	6.110	1449.01	4.3696	1449.01	4.3647
303.08	7.100	1451.87	4.3790	1451.87	4.3738
303.09	8.120	1454.74	4.3884	1454.78	4.3832
303.09	9.110	1457.50	4.3976	1457.53	4.3923
303.09	10.13	1460.29	4.4065	1460.30	4.4017
303.09	11.13	1463.00	4.4158	1463.01	4.4109
303.09	12.12	1465.62	4.4243	1465.63	4.4200
303.09	13.09	1468.13	4.4326	1468.14	4.4289
303.09	14.11	1470.78	4.4413	1470.79	4.4383
303.09	15.12	1473.31	4.4499	1473.35	4.4476

TABLE 1 – Values of Dielectric Constant of HCFC 123 (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$e(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$e(T_n,p)$
$T_n=298.71$ K					
298.70	0.210	1441.72	4.3918	1441.71	4.4051
298.70	1.120	1444.54	4.4006	1444.51	4.4133
298.71	2.105	1447.51	4.4107	1447.51	4.4223
298.71	3.095	1450.45	4.4205	1450.45	4.4313
298.71	4.100	1453.40	4.4303	1453.40	4.4404
298.71	5.110	1456.31	4.4399	1456.31	4.4496
298.70	6.140	1459.23	4.4500	1459.20	4.4590
298.71	7.110	1461.88	4.4587	1461.88	4.4678
298.72	8.100	1464.57	4.4676	1464.60	4.4768
298.72	9.120	1467.32	4.4768	1467.33	4.4860
298.72	10.11	1469.92	4.4854	1469.95	4.4950
298.72	11.12	1472.54	4.4942	1472.55	4.5042
298.72	12.10	1475.03	4.5026	1475.06	4.5131
298.72	13.10	1477.56	4.5111	1477.57	4.5222
298.72	14.10	1480.04	4.5194	1480.05	4.5313
298.72	15.10	1482.48	4.5277	1482.51	4.5404
$T_n=288.71$ K					
288.70	0.210	1466.18	4.5927	1466.17	4.6042
288.70	1.115	1468.71	4.6010	1468.70	4.6122
288.70	2.130	1471.51	4.6110	1471.48	4.6212
288.70	3.110	1474.18	4.6201	1474.14	4.6298
288.70	4.110	1476.82	4.6293	1476.81	4.6387
288.71	5.120	1479.45	4.6386	1479.45	4.6476
288.71	6.110	1482.01	4.6474	1482.01	4.6564
288.71	7.100	1484.52	4.6561	1484.52	4.6651
288.71	8.110	1487.05	4.6648	1487.05	4.6741
288.71	9.100	1489.49	4.6733	1489.49	4.6828
288.71	10.10	1491.90	4.6820	1491.90	4.6917
288.71	11.11	1494.33	4.6904	1494.33	4.7006
288.72	12.11	1496.65	4.6987	1496.65	4.7094
288.72	13.11	1498.97	4.7069	1499.00	4.7183
288.72	14.11	1501.27	4.7150	1501.30	4.7271
288.72	15.10	1503.50	4.7228	1503.53	4.7359

TABLE 1 – Values of Dielectric Constant of HCFC 123 (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$\epsilon(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$\epsilon(T_n,p)$
$T_n=278.02$ K					
278.01	0.210	1491.8	4.8224	1491.79	4.8176
278.02	1.115	1494.06	4.8305	1494.06	4.8254
278.02	2.100	1496.53	4.8395	1496.53	4.8339
278.02	3.105	1499.01	4.8481	1499.01	4.8425
278.02	4.110	1501.43	4.8569	1501.43	4.8511
278.02	5.110	1503.83	4.8655	1503.83	4.8597
278.02	6.105	1506.15	4.8740	1506.15	4.8682
278.02	7.110	1508.50	4.8825	1508.50	4.8769
278.02	8.105	1510.78	4.8907	1510.78	4.8854
278.02	9.100	1513.02	4.8993	1513.02	4.8940
278.02	10.11	1515.27	4.9075	1515.27	4.9026
278.02	11.12	1517.49	4.9155	1517.49	4.9113
278.02	12.11	1519.62	4.9233	1519.62	4.9198
278.02	13.11	1521.76	4.9309	1521.76	4.9284
278.02	14.12	1523.89	4.9388	1523.89	4.9371
278.03	15.10	1525.94	4.9461	1525.94	4.9455
$T_n=268.02$ K					
268.01	0.210	1515.41	5.0525	1515.39	5.0470
268.01	1.120	1517.52	5.0600	1517.50	5.0546
268.02	2.110	1519.75	5.0684	1519.75	5.0628
268.02	3.100	1521.99	5.0765	1521.99	5.0710
268.02	4.110	1524.23	5.0850	1524.23	5.0794
268.02	5.120	1526.45	5.0934	1526.45	5.0878
268.02	6.120	1528.62	5.1016	1528.62	5.0961
268.02	7.115	1530.74	5.1094	1530.74	5.1044
268.03	8.115	1532.83	5.1171	1532.85	5.1127
268.03	9.110	1534.90	5.1251	1534.92	5.1209
268.03	10.12	1537.00	5.1330	1537.02	5.1293
268.03	11.10	1538.98	5.1407	1539.01	5.1375
268.03	12.11	1541.01	5.1484	1541.03	5.1458
268.03	13.11	1543.00	5.1556	1543.02	5.1542
268.03	14.12	1545.00	5.1633	1545.00	5.1625
268.03	15.10	1546.88	5.1705	1546.90	5.1706

TABLE 1 – Values of Dielectric Constant of HCFC 123 (cont'd)

T / K	p / MPa	r (T,p) / kg.m ⁻³	e (T,p)	r (T _n ,p) / kg.m ⁻³	e (T _n ,p)
T_n=258.08 K					
256.07	0.210	1543.26	5.3470	1543.23	5.2941
256.07	1.120	1545.17	5.3541	1545.15	5.3014
256.07	2.110	1547.21	5.3621	1547.18	5.3093
256.08	3.110	1549.23	5.3699	1549.23	5.3173
256.08	4.100	1551.24	5.3778	1551.24	5.3253
256.08	5.100	1553.24	5.3855	1553.24	5.3333
256.08	6.095	1555.19	5.3929	1555.19	5.3412
256.08	7.100	1557.16	5.4009	1557.16	5.3493
256.08	8.100	1559.08	5.4082	1559.08	5.3573
256.08	9.100	1560.99	5.4159	1560.99	5.3653
256.08	10.10	1562.88	5.4235	1562.88	5.3733
256.08	11.10	1564.73	5.4309	1564.73	5.3813
256.08	12.12	1566.61	5.4381	1566.61	5.3895
256.08	13.11	1568.42	5.4458	1568.42	5.3974
256.08	14.12	1570.26	5.4526	1570.26	5.4055
256.09	15.12	1572.01	5.4599	1572.03	5.4135
T_n=247.58 K					
247.56	0.210	1562.99	5.5736	1562.92	5.5612
247.57	1.120	1564.73	5.5803	1564.71	5.5682
247.57	2.120	1566.68	5.5882	1566.64	5.5758
247.57	3.100	1568.54	5.5955	1568.52	5.5834
247.57	4.105	1570.44	5.6034	1570.42	5.5911
247.58	5.120	1572.32	5.6109	1572.32	5.5989
247.58	6.105	1574.14	5.6182	1574.14	5.6065
247.58	7.100	1575.97	5.6257	1575.97	5.6141
247.58	8.115	1577.79	5.6332	1577.79	5.6219
247.58	9.110	1579.58	5.6403	1579.58	5.6295
247.58	10.11	1581.36	5.6477	1581.36	5.6372
247.58	11.10	1583.11	5.6547	1583.11	5.6448
247.58	12.12	1584.88	5.6622	1584.87	5.6527
247.59	13.11	1586.55	5.6691	1586.57	5.6603
247.59	14.11	1588.26	5.6758	1588.28	5.6680
247.59	15.12	1589.96	5.6827	1589.98	5.6757

TABLE 1 – Values of Dielectric Constant of HCFC 123 (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$e(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$e(T_n,p)$
$T_n=237.94$ K					
237.91	0.210	1585.29	5.8514	1585.21	5.8506
237.92	1.090	1586.85	5.8577	1586.81	5.8571
237.92	2.090	1588.64	5.8645	1588.60	5.8644
237.93	3.110	1590.43	5.8723	1590.41	5.8719
237.93	4.105	1592.19	5.8795	1592.17	5.8792
237.94	5.115	1593.93	5.8867	1593.93	5.8866
237.94	6.095	1595.63	5.8936	1595.63	5.8938
237.94	7.120	1597.36	5.9009	1597.36	5.9013
237.96	8.120	1599.02	5.9077	1599.06	5.9086
237.96	9.105	1600.67	5.9145	1600.71	5.9159
237.96	10.11	1602.34	5.9217	1602.38	5.9232
237.96	11.12	1604.01	5.9287	1604.04	5.9306
237.96	12.11	1605.61	5.9355	1605.64	5.9379
237.96	13.12	1607.25	5.9424	1607.29	5.9453
237.96	14.10	1608.8	5.9489	1608.83	5.9525
237.96	15.11	1610.41	5.9556	1610.45	5.9599
$T_n=228.28$ K					
228.23	0.200	1607.64	6.1554	1607.53	6.1654
228.23	1.110	1609.19	6.1617	1609.05	6.1717
228.24	2.130	1610.86	6.1691	1610.77	6.1788
228.24	3.115	1612.5	6.1752	1612.41	6.1857
228.24	4.125	1614.14	6.1822	1614.05	6.1927
228.29	5.120	1615.65	6.1884	1615.67	6.1996
228.29	6.130	1617.27	6.1949	1617.31	6.2066
228.29	7.120	1618.85	6.2020	1618.89	6.2135
228.30	8.110	1620.41	6.2087	1620.46	6.2204
228.30	9.120	1621.99	6.2154	1622.05	6.2274
228.30	10.11	1623.52	6.2214	1623.58	6.2343
228.30	11.11	1625.08	6.2283	1625.11	6.2412
228.31	12.12	1626.60	6.2350	1626.67	6.2483
228.31	13.10	1628.07	6.2411	1628.15	6.2551
228.31	14.11	1629.60	6.2480	1629.67	6.2621
228.31	15.13	1631.09	6.2547	1631.17	6.2691

TABLE 1 – Values of Dielectric Constant of HCFC 123 (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$e(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$e(T_n,p)$
$T_n=218.85$ K					
218.84	0.210	1629.43	6.4790	1629.42	6.5092
218.84	1.110	1630.87	6.4849	1630.83	6.5151
218.85	2.120	1632.42	6.4916	1632.42	6.5217
218.85	3.110	1633.97	6.4985	1633.97	6.5282
218.85	4.105	1635.49	6.5050	1635.49	6.5346
218.85	5.105	1637.01	6.5121	1637.01	6.5412
218.85	6.110	1638.54	6.5188	1638.54	6.5477
218.84	7.120	1640.06	6.5257	1640.04	6.5543
218.85	8.105	1641.52	6.5322	1641.52	6.5608
218.86	9.120	1642.97	6.5385	1643.01	6.5674
218.86	10.12	1644.43	6.5444	1644.47	6.5739
218.86	11.11	1645.89	6.5509	1645.90	6.5804
218.86	12.13	1647.35	6.5574	1647.37	6.5871
218.86	13.11	1648.75	6.5634	1648.76	6.5935
218.86	14.12	1650.15	6.5699	1650.19	6.6000
218.87	15.12	1651.55	6.5764	1651.61	6.6066
$T_n=208.57$ K					
208.48	0.210	1653.65	6.8750	1653.44	6.8860
208.48	1.120	1654.99	6.8809	1654.78	6.8915
208.50	2.125	1656.42	6.8870	1656.25	6.8976
208.51	3.120	1657.82	6.8931	1657.69	6.9036
208.55	4.120	1659.17	6.8982	1659.12	6.9097
208.60	5.120	1660.47	6.9029	1660.55	6.9158
208.60	6.120	1661.88	6.9089	1661.96	6.9218
208.60	7.120	1663.28	6.9148	1663.36	6.9279
208.58	8.120	1664.72	6.9218	1664.75	6.9340
208.59	9.125	1666.10	6.9288	1666.14	6.9401
208.60	10.13	1667.44	6.9344	1667.52	6.9462
208.60	11.12	1668.79	6.9403	1668.85	6.9522
208.60	12.10	1670.10	6.9462	1670.18	6.9582
208.60	13.13	1671.49	6.9527	1671.57	6.9644
208.61	14.13	1672.79	6.9587	1672.88	6.9705
208.62	15.09	1674.05	6.9640	1674.15	6.9763

TABLE 1 – Values of Dielectric Constant of HCFC 123 (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$e(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$e(T_n,p)$
$T_n=204.04$ K					
203.97	0.215	1664.27	7.0642	1664.11	7.0883
203.98	1.105	1665.54	7.0686	1665.39	7.0934
204.02	2.105	1666.85	7.0738	1666.81	7.0993
204.06	3.115	1668.18	7.0787	1668.22	7.1052
204.08	4.105	1669.51	7.0837	1669.60	7.1109
204.10	5.100	1670.85	7.0890	1670.97	7.1167
204.06	6.140	1672.36	7.0966	1672.40	7.1228
204.06	7.140	1673.73	7.1029	1673.77	7.1286
204.06	8.115	1675.04	7.1089	1675.08	7.1343
204.06	9.135	1676.41	7.1151	1676.45	7.1402
204.06	10.14	1677.75	7.1215	1677.79	7.1461
204.04	11.14	1679.11	7.1284	1679.11	7.1519
204.02	12.16	1680.48	7.1355	1680.44	7.1579
204.02	13.10	1681.71	7.1411	1681.66	7.1634
204.00	14.11	1683.05	7.1478	1682.97	7.1692
203.99	15.11	1684.38	7.1554	1684.26	7.1751

TABLE 2 – Values of Dielectric Constant of HFC 152a.

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$\epsilon(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$\epsilon(T_n,p)$
$T_n=297.84$ K					
297.85	16.81	947.30	13.402	947.32	13.306
297.84	15.99	945.38	13.366	945.38	13.265
297.84	14.97	942.91	13.320	942.91	13.214
297.84	13.98	940.47	13.275	940.47	13.164
297.84	12.97	937.91	13.229	937.91	13.113
297.84	12.00	935.40	13.182	935.40	13.064
297.84	10.94	932.58	13.130	932.58	13.011
297.84	10.06	930.19	13.082	930.19	12.967
297.85	9.020	927.26	13.026	927.28	12.915
297.84	7.980	924.30	12.969	924.30	12.863
297.84	6.880	921.04	12.912	921.04	12.807
297.84	5.960	918.23	12.855	918.23	12.761
297.84	5.070	915.44	12.804	915.44	12.716
297.84	4.100	912.30	12.745	912.30	12.668
297.84	3.000	908.61	12.678	908.61	12.612
297.84	1.990	905.10	12.613	905.10	12.562
297.84	0.980	901.45	12.547	901.45	12.511
297.84	0.600	900.03	12.520	900.03	12.492
$T_n=288.32$ K					
288.33	16.71	965.71	14.244	965.73	14.225
288.33	15.34	962.73	14.186	962.75	14.158
288.32	14.46	960.79	14.148	960.79	14.115
288.32	13.48	958.57	14.106	958.57	14.067
288.31	12.48	956.28	14.061	956.26	14.018
288.31	11.48	953.92	14.015	953.90	13.969
288.31	10.46	951.45	13.968	951.43	13.920
288.31	9.550	949.21	13.923	949.19	13.875
288.31	8.540	946.66	13.874	946.64	13.826
288.31	7.490	943.94	13.820	943.92	13.775
288.31	6.520	941.36	13.769	941.34	13.727
288.31	5.500	938.58	13.714	938.56	13.677
288.32	4.470	935.67	13.653	935.67	13.627
288.32	3.570	933.08	13.604	933.08	13.583
288.32	2.570	930.12	13.547	930.12	13.534
288.32	1.530	926.94	13.486	926.94	13.484
288.32	0.550	923.84	13.427	923.84	13.436

TABLE 2 – Values of Dielectric Constant of HFC 152a (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$\epsilon(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$\epsilon(T_n,p)$
$T_n=278.61$ K					
278.62	17.14	985.19	15.189	985.21	15.235
278.61	15.97	982.91	15.141	982.91	15.180
278.61	14.95	980.87	15.099	980.87	15.132
278.61	13.99	978.91	15.060	978.91	15.086
278.61	12.96	976.78	15.015	976.78	15.037
278.61	12.02	974.79	14.976	974.79	14.993
278.60	11.10	972.83	14.935	972.81	14.949
278.60	9.990	970.40	14.884	970.37	14.897
278.60	9.040	968.27	14.842	968.25	14.852
278.60	7.990	965.86	14.792	965.84	14.802
278.60	7.010	963.57	14.745	963.55	14.756
278.60	6.000	961.15	14.695	961.13	14.708
278.61	5.050	958.81	14.644	958.81	14.663
278.61	4.010	956.20	14.590	956.20	14.614
278.61	3.000	953.61	14.536	953.61	14.566
278.61	1.970	950.89	14.481	950.89	14.517
278.61	0.990	948.23	14.428	948.23	14.471
278.61	0.550	947.02	14.404	947.02	14.450
$T_n=268.29$ K					
268.30	16.99	1004.29	16.241	1004.31	16.292
268.30	16.00	1002.52	16.203	1002.54	16.246
268.30	14.97	1000.65	16.162	1000.67	16.199
268.29	13.96	998.80	16.122	998.80	16.153
268.29	13.00	997.00	16.084	997.00	16.109
268.29	12.02	995.13	16.043	995.13	16.064
268.29	10.98	993.12	16.000	993.12	16.017
268.30	9.860	990.88	15.949	990.90	15.966
268.30	8.980	989.11	15.911	989.13	15.925
268.29	7.990	987.10	15.867	987.10	15.880
268.29	6.990	985.02	15.822	985.02	15.835
268.29	6.000	982.91	15.776	982.91	15.789
268.29	4.980	980.70	15.729	980.70	15.743
268.29	3.990	978.50	15.682	978.50	15.697
268.28	3.000	976.28	15.635	976.26	15.652
268.28	2.000	973.97	15.584	973.95	15.606
268.28	0.990	971.58	15.534	971.56	15.560
268.28	0.550	970.52	15.510	970.50	15.540

TABLE 2 – Values of Dielectric Constant of HFC 152a (cont'd)

T / K	p / MPa	$\mathbf{r}(T,p)$ / kg.m ⁻³	$\mathbf{e}(T,p)$	$\mathbf{r}(T_n,p)$ / kg.m ⁻³	$\mathbf{e}(T_n,p)$
$T_n=255.86$ K					
255.88	17.18	1027.50	17.644	1027.53	17.446
255.88	15.97	1025.56	17.600	1025.60	17.393
255.87	15.00	1024.00	17.564	1024.02	17.350
255.87	13.97	1022.30	17.526	1022.32	17.305
255.86	12.98	1020.67	17.488	1020.67	17.261
255.86	11.99	1018.99	17.449	1018.99	17.218
255.86	10.99	1017.27	17.409	1017.27	17.174
255.86	9.990	1015.52	17.369	1015.52	17.130
255.86	8.970	1013.71	17.328	1013.71	17.085
255.86	7.990	1011.95	17.286	1011.95	17.042
255.86	6.990	1010.11	17.245	1010.11	16.998
255.86	6.000	1008.27	17.204	1008.27	16.954
255.86	5.000	1006.38	17.159	1006.38	16.910
255.86	4.000	1004.45	17.115	1004.45	16.866
255.86	2.980	1002.45	17.069	1002.45	16.822
255.85	1.980	1000.47	17.024	1000.45	16.778
255.86	0.990	998.43	16.976	998.43	16.734
255.86	0.540	997.50	16.955	997.50	16.714
$T_n=247.36$ K					
247.38	17.94	1044.02	18.716	1044.05	18.716
247.37	16.99	1042.64	18.684	1042.65	18.676
247.37	15.98	1041.13	18.649	1041.15	18.633
247.37	15.00	1039.65	18.612	1039.67	18.592
247.37	14.00	1038.13	18.575	1038.14	18.550
247.37	12.99	1036.56	18.537	1036.58	18.508
247.36	12.02	1035.06	18.501	1035.06	18.467
247.36	11.01	1033.45	18.463	1033.45	18.424
247.36	9.990	1031.81	18.423	1031.81	18.381
247.36	9.110	1030.37	18.390	1030.37	18.344
247.36	8.000	1028.53	18.345	1028.53	18.297
247.36	6.990	1026.83	18.303	1026.83	18.255
247.36	6.000	1025.14	18.263	1025.14	18.213
247.36	5.000	1023.41	18.222	1023.41	18.171
247.36	4.010	1021.67	18.182	1021.67	18.129
247.36	3.010	1019.88	18.139	1019.88	18.087
247.36	2.010	1018.06	18.094	1018.06	18.045
247.36	1.030	1016.25	18.052	1016.25	18.004
247.36	0.540	1015.33	18.030	1015.33	17.983

TABLE 2 – Values of Dielectric Constant of HFC 152a (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$\epsilon(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$\epsilon(T_n,p)$
$T_n=237.97$ K					
237.98	16.97	1059.44	19.931	1059.45	20.017
237.98	15.97	1058.06	19.908	1058.08	19.977
237.97	15.00	1056.73	19.875	1056.73	19.938
237.97	14.00	1055.32	19.838	1055.32	19.898
237.97	13.00	1053.89	19.803	1053.89	19.858
237.97	12.00	1052.45	19.766	1052.45	19.818
237.97	11.00	1050.99	19.729	1050.99	19.778
237.96	10.00	1049.53	19.692	1049.51	19.738
237.96	9.000	1048.03	19.654	1048.01	19.698
237.96	8.000	1046.51	19.619	1046.49	19.658
237.96	7.010	1044.99	19.578	1044.97	19.618
237.96	6.000	1043.42	19.540	1043.40	19.578
237.96	4.990	1041.82	19.499	1041.81	19.537
237.96	4.000	1040.24	19.460	1040.22	19.498
237.96	3.000	1038.62	19.419	1038.60	19.458
237.96	2.000	1036.97	19.378	1036.95	19.418
237.96	1.000	1035.30	19.338	1035.28	19.378
237.96	0.540	1034.52	19.316	1034.50	19.359
$T_n=228.23$ K					
228.24	17.93	1077.89	21.414	1077.91	21.514
228.24	16.96	1076.67	21.383	1076.69	21.477
228.24	15.99	1075.43	21.351	1075.45	21.440
228.24	14.99	1074.15	21.316	1074.17	21.402
228.23	13.98	1072.86	21.283	1072.86	21.364
228.23	12.99	1071.56	21.246	1071.56	21.327
228.23	11.99	1070.23	21.211	1070.23	21.289
228.23	10.99	1068.89	21.176	1068.89	21.251
228.23	9.900	1067.41	21.140	1067.41	21.210
228.23	9.000	1066.18	21.104	1066.18	21.176
228.23	7.990	1064.78	21.068	1064.78	21.137
228.23	6.990	1063.37	21.031	1063.37	21.100
228.23	6.000	1061.97	20.992	1061.97	21.062
228.23	5.000	1060.53	20.954	1060.53	21.024
228.23	3.990	1059.06	20.914	1059.06	20.986
228.23	3.000	1057.60	20.877	1057.60	20.949
228.23	2.000	1056.10	20.838	1056.10	20.911
228.23	0.990	1054.58	20.798	1054.58	20.872
228.23	0.540	1053.89	20.780	1053.89	20.855

TABLE 2 – Values of Dielectric Constant of HFC 152a (cont'd)

T / K	p / MPa	$r(T,p)$ / kg.m ⁻³	$\epsilon(T,p)$	$r(T_n,p)$ / kg.m ⁻³	$\epsilon(T_n,p)$
$T_n=218.95$ K					
218.93	16.60	1092.55	22.902	1092.51	23.058
218.93	15.60	1091.36	22.870	1091.33	23.023
218.93	14.60	1090.17	22.834	1090.13	22.987
218.93	13.60	1088.96	22.799	1088.93	22.952
218.94	12.57	1087.69	22.763	1087.67	22.915
218.94	11.60	1086.49	22.728	1086.48	22.881
218.94	10.59	1085.24	22.694	1085.22	22.845
218.94	9.550	1083.93	22.658	1083.91	22.808
218.94	8.600	1082.73	22.626	1082.71	22.775
218.94	7.600	1081.44	22.589	1081.43	22.739
218.97	6.620	1080.12	22.547	1080.16	22.704
218.97	5.590	1078.77	22.509	1078.81	22.668
218.97	4.560	1077.40	22.473	1077.44	22.631
218.97	3.580	1076.09	22.435	1076.13	22.597
218.97	2.530	1074.67	22.395	1074.70	22.559
218.98	1.640	1073.43	22.360	1073.48	22.528
218.98	0.540	1071.90	22.318	1071.96	22.489
$T_n=211.02$ K					
211.05	17.87	1107.64	24.376	1107.69	23.955
211.05	16.60	1106.24	24.336	1106.30	23.912
211.04	15.59	1105.14	24.303	1105.17	23.877
211.03	14.52	1103.96	24.269	1103.98	23.841
210.99	13.48	1102.85	24.244	1102.80	23.805
210.99	12.56	1101.80	24.215	1101.75	23.774
210.99	11.52	1100.60	24.178	1100.55	23.738
211.00	10.52	1099.42	24.144	1099.39	23.704
211.00	9.600	1098.34	24.113	1098.31	23.673
211.00	8.560	1097.11	24.077	1097.07	23.637
211.00	7.540	1095.89	24.039	1095.85	23.602
211.01	6.520	1094.64	24.003	1094.62	23.567
211.01	5.550	1093.45	23.969	1093.44	23.534
211.02	4.510	1092.15	23.930	1092.15	23.499
211.02	3.540	1090.94	23.892	1090.94	23.466
211.03	2.540	1089.67	23.853	1089.68	23.432
211.03	1.540	1088.39	23.815	1088.41	23.397
211.04	0.550	1087.10	23.777	1087.14	23.364

TABLE 2 – Values of Dielectric Constant of HFC 152a (cont'd)

T / K	p / MPa	$\mathbf{r}(T,p)$ / kg.m ⁻³	$\mathbf{e}(T,p)$	$\mathbf{r}(T_n,p)$ / kg.m ⁻³	$\mathbf{e}(T_n,p)$
$T_n=207.09$ K					
207.14	17.48	1113.94	25.135	1114.03	24.835
207.14	16.46	1112.85	25.103	1112.94	24.802
207.13	15.48	1111.81	25.070	1111.88	24.769
207.13	14.49	1110.74	25.041	1110.81	24.737
207.12	13.49	1109.66	25.008	1109.71	24.704
207.12	12.50	1108.56	24.976	1108.62	24.672
207.12	11.49	1107.44	24.941	1107.49	24.639
207.12	10.45	1106.26	24.908	1106.32	24.605
207.11	9.500	1105.20	24.876	1105.24	24.573
207.10	8.520	1104.10	24.843	1104.12	24.541
207.09	7.400	1102.82	24.806	1102.82	24.504
207.08	6.450	1101.73	24.773	1101.71	24.473
207.04	5.430	1100.60	24.744	1100.50	24.440
207.04	4.440	1099.42	24.713	1099.32	24.407
207.03	3.450	1098.24	24.680	1098.13	24.375
207.02	2.500	1097.11	24.648	1096.98	24.344
207.01	1.520	1095.93	24.614	1095.78	24.312
207.00	0.560	1094.76	24.581	1094.59	24.280

TABLE 3 – Values of the coefficients of equations (1) and (2).

Sample	a_0	a_l/ K	b_0/ MPa^{-1}	$b_l/ \text{K MPa}^{-1}$	s
HCFC123	-1.336±0.006	1711.1± 1.4	0.0161±0.0006	-2.1±0.2	0.0057
HFC 152a	-14.829±0.007	8136.7±17.4	0.090±0.007	-12.0±1.7	0.0602
Sample	c_0	c_l/ K	$d_0/ \text{m}^2.\text{kg}^{-1}$	$d_l/ \text{K.m}^3.\text{kg}^{-1}$	s
HCFC123	1.77±0.03	-625.99±14.2	-0.0005±0.00002	1.122±0.008	0.0026
HFC 152a	15.9±0.2	-6842.1±87.1	- 0.0145±0.0002	10.79±0.068	0.0168

TABLE 4 – Values of the coefficients of equation (3) for HCFC 123.

T/ K	$r_{sat}/ \text{kg.m}^{-3}$	$e(r_{sat})$	$-A$	$B \times 10^4$
204.04	1663.80	7.0621	4.27426	-58
208.57	1653.14	6.8733	4.13237	-25
218.85	1629.08	6.4771	4.22195	0.2
228.28	1607.19	6.1537	4.09763	-10
237.94	1584.84	5.8494	4.07975	-0.7
247.58	1562.53	5.5715	4.02208	-0.4
256.08	1542.83	5.3452	3.92589	-0.9
268.02	1514.95	5.0506	3.79198	-0.7
278.02	1491.36	4.8208	3.69080	-0.6
288.71	1465.75	4.5911	3.57169	-0.6
298.71	1441.34	4.3903	3.43493	-0.3
303.08	1430.51	4.3092	3.38760	-0.7
312.91	1405.69	4.1323	3.27289	0.2

TABLE 5 – Values of the coefficients of equation (3) for HFC 152a.

T/ K	$r_{sat}/ \text{kg.m}^{-3}$	$e(r_{sat})$	$-A$	$B \times 10^4$
207.09	1093.90	24.5585	9.53895	-5.8
211.02	1086.44	23.7549	9.72639	7.4
218.95	1071.23	22.2984	9.6139	-0.7
228.23	1053.12	20.7584	9.15874	0.2
237.97	1033.68	19.2925	8.77228	2.2
247.36	1014.49	18.0099	8.54706	-0.6
255.86	996.66	16.9361	8.29931	0.9
268.29	969.70	15.4926	7.95810	-0.5
278.61	946.38	14.3887	7.65888	1.6
288.32	923.49	13.4174	7.35069	2.6
297.84	900.00	12.5185	7.07873	-0.2

TABLE 6 – Values of A' according to equation (4).

HCFC123		HFC152a	
T / K	-A'	T / K	-A'
204.04	4.07012	207.09	9.40158
208.57	4.04600	211.02	9.89336
218.85	4.22257	218.95	9.59596
228.28	4.05785	228.23	9.16248
237.94	4.05994	237.97	8.81132
247.58	4.01324	247.36	8.53744
256.08	3.90635	255.86	8.31231
268.02	3.77787	268.29	7.95161
278.02	3.67977	278.61	7.67626
288.71	3.56151	288.32	7.37541
298.71	3.43045	297.84	7.07732
303.08	3.37813		
312.91	3.27563		

TABLE 7 – Values of the Kirkwood factor g and the dipole moment

Fluid	n^*	n / D [20]	g
HCFC 123	2.13	1.36	2.48
HFC 152a	3.69	2.26	2.67
HFC 32	3.60	1.98	3.31
HCFC 141b	2.96	2.01	2.17
HCFC 142b	3.17	2.14	2.20
HFC 134a	3.54	1.91 [5]	3.44

FIGURE CAPTIONS

Figure 1 – Dielectric Constant of HCFC 123 as a function of pressure for several isotherms.

Figure 2 – Dielectric Constant of HCFC 123 as a function of density for several isotherms.

Figure 3 – Dielectric Constant of HFC 152a as a function of pressure for several isotherms.

Figure 4 – Dielectric Constant of HFC 152a as a function of density for several isotherms.

Figure 5 -Deviation [$100(\epsilon_{\text{exp}} - \epsilon_{\text{cor}})/ \epsilon_{\text{exp}}$] of the experimental data from equation (1).

Figure 6 –Deviation [$100(\epsilon_{\text{exp}} - \epsilon_{\text{cor}})/ \epsilon_{\text{exp}}$] of the experimental data from equation (2).

Figure 7 – Eulerian representation for HCFC 123 (equation (3)).

Figure 8 – Eulerian representation for HFC 152a (equation (3)).

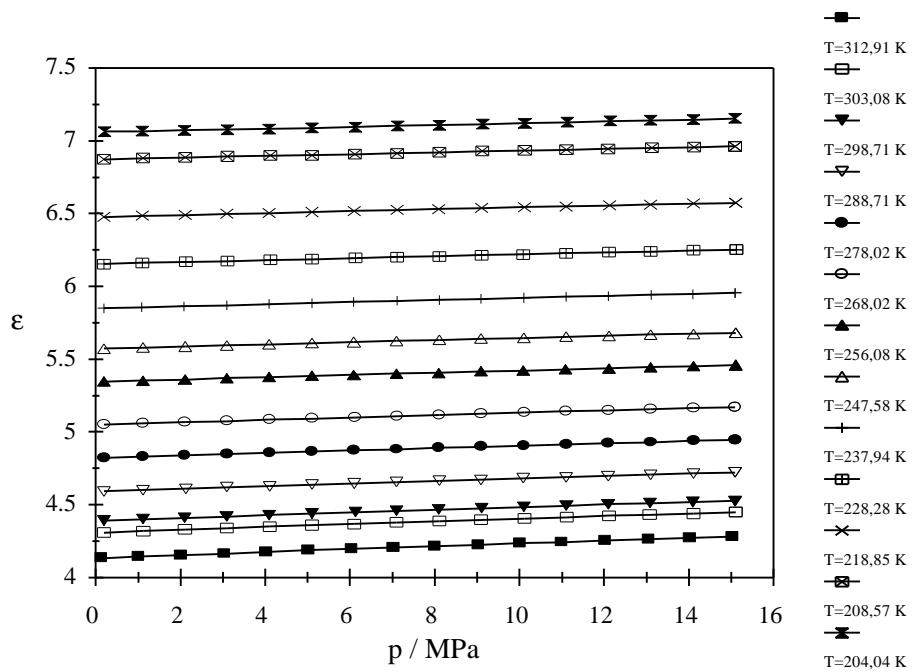


Figure 1 – Dielectric Constant of HCFC 123 as a function of pressure
for several isotherms.

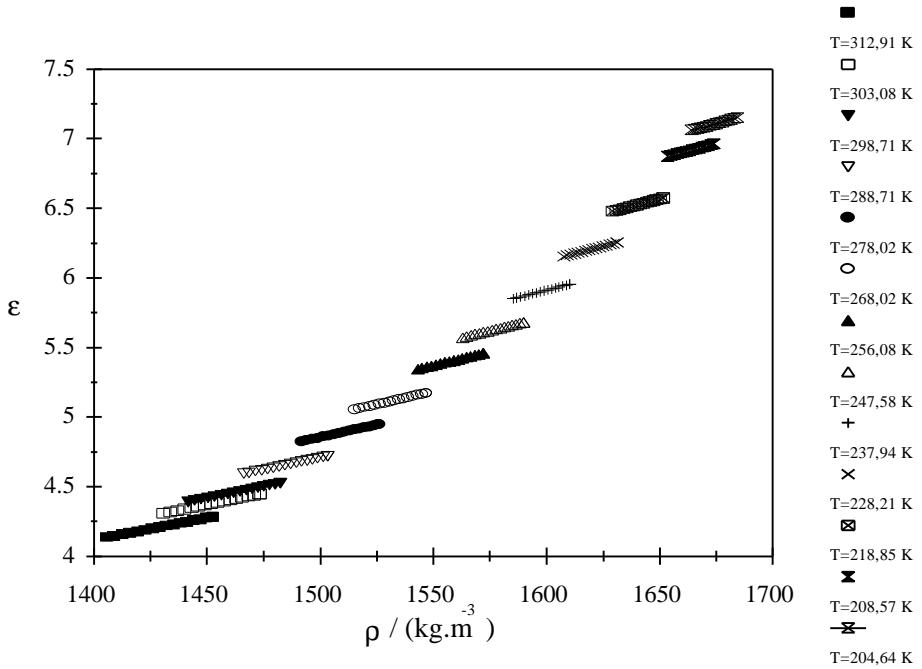


Figure 2 – Dielectric Constant of HCFC 123 as a function of density
for several isotherms.

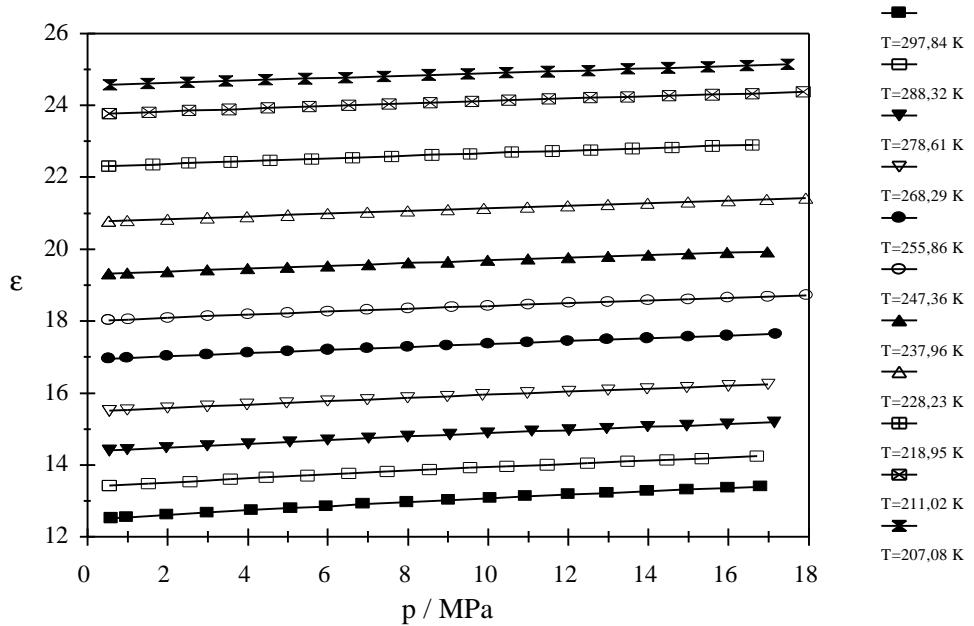


Figure 3 – Dielectric Constant of HFC 152a as a function of pressure for several isotherms.

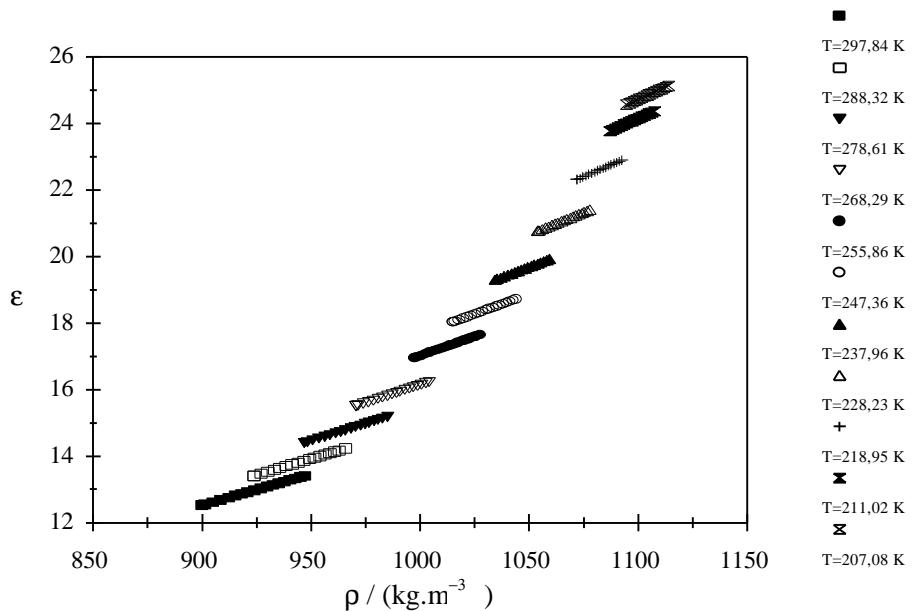


Figure 4 – Dielectric Constant of HFC 152a as a function of density for several isotherms.

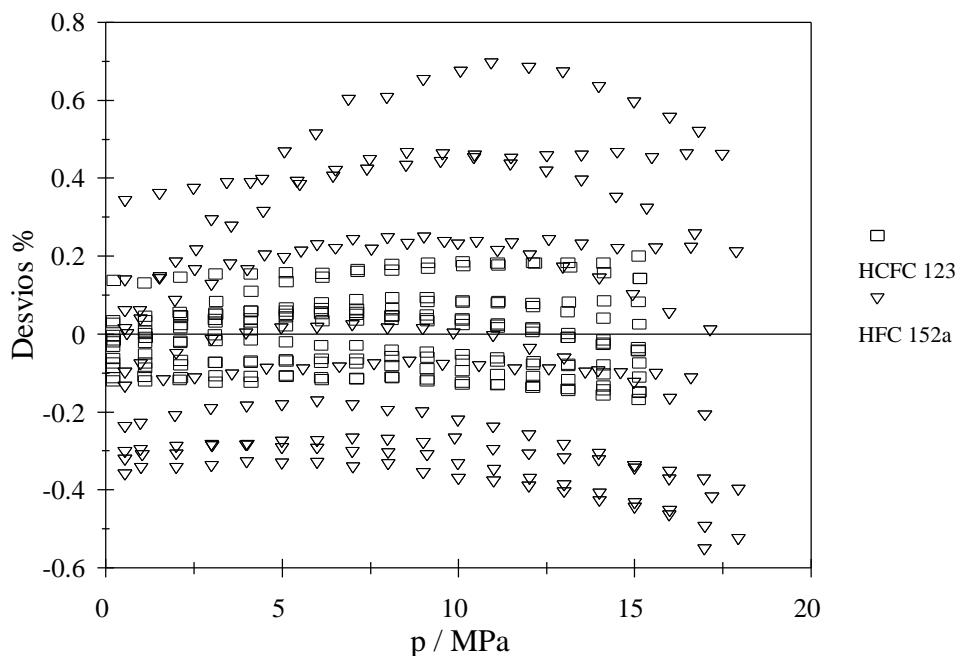


Figure 5 -Deviation [$100(\epsilon_{\text{exp}} - \epsilon_{\text{cor}})/\epsilon_{\text{exp}}$] of the experimental data from equation (1).

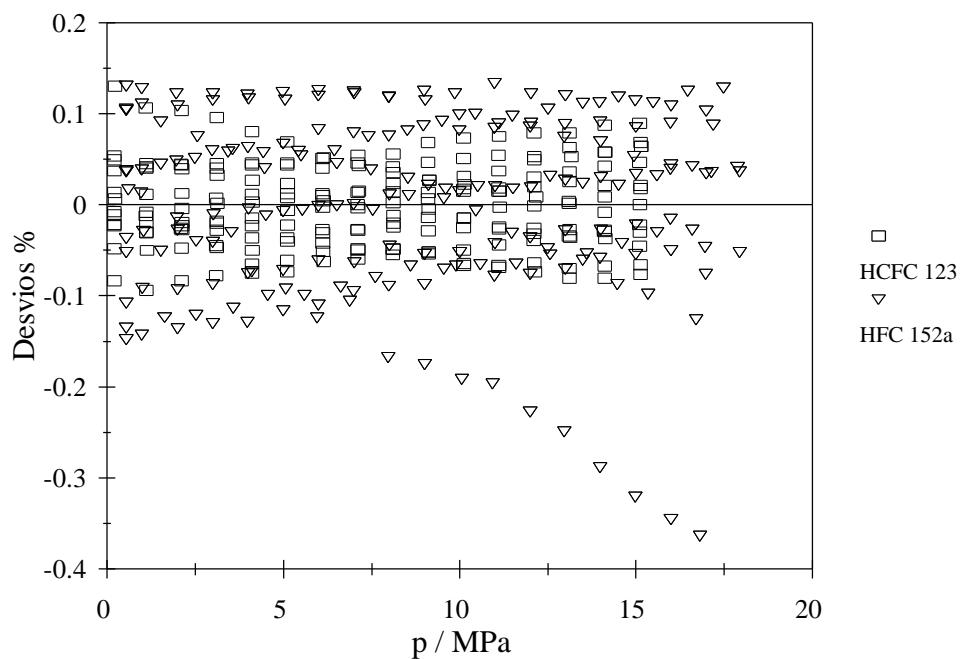


Figure 6 –Deviation [$100(\epsilon_{\text{exp}} - \epsilon_{\text{cor}})/\epsilon_{\text{exp}}$] of the experimental data from equation (2).

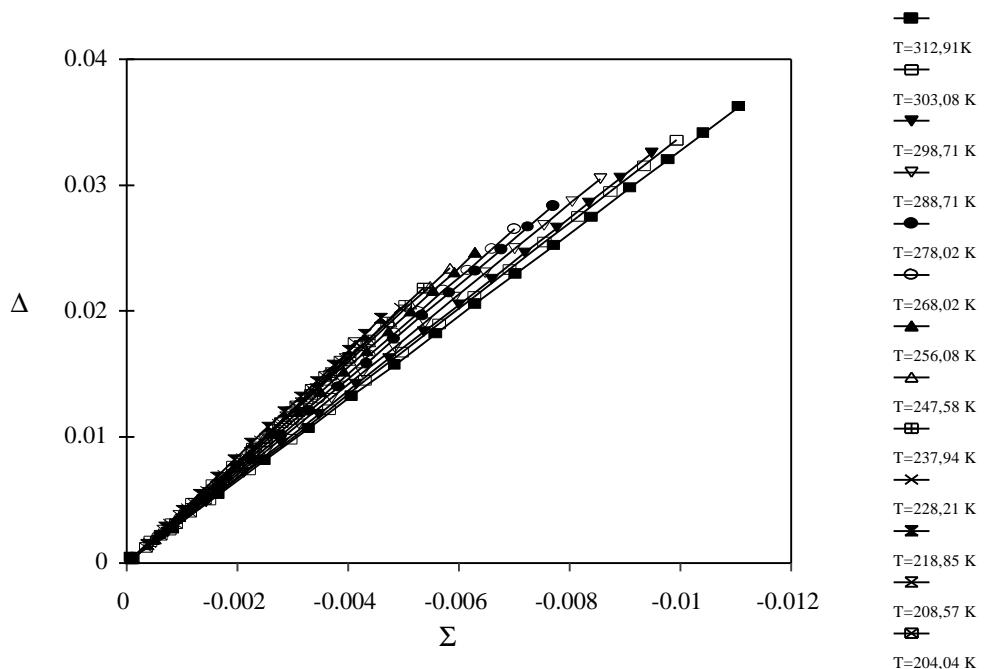


Figure 7 – Eulerian representation for HCFC 123 (equation (3)).

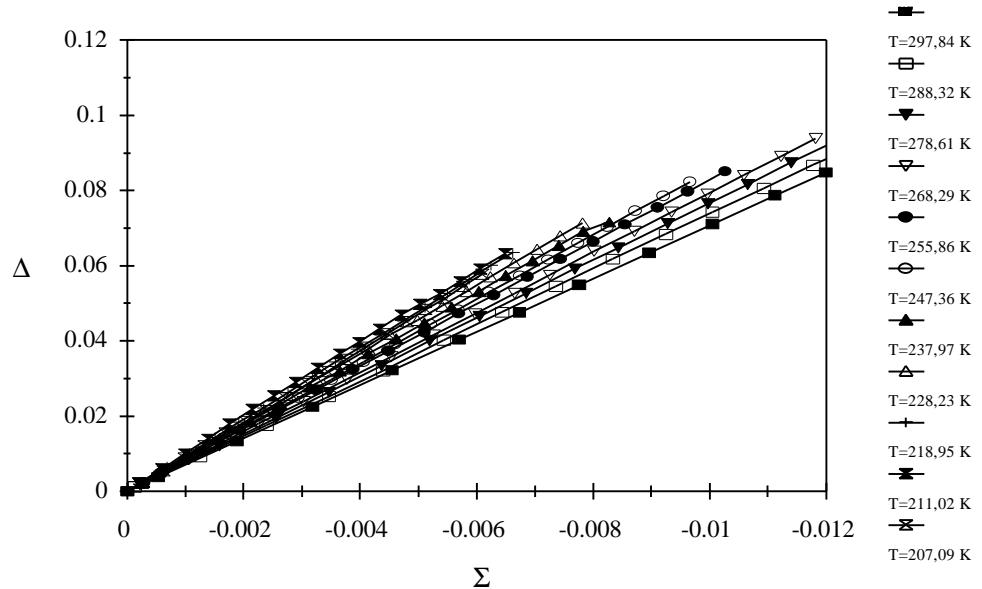


Figure 8 – Eulerian representation for HFC 152a (equation (3)).